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REVIEW/MISE AU POINT

Long-term EEG in adults: Sleep-deprived EEG (SDE), ambulatory EEG (Amb-EEG) and long-term video-EEG recording (LTVER)

L'EEG prolongé de l'adulte : EEG prolongé après privation de sommeil (EPPS), EEG ambulatoire (Amb-EEG) et vidéo-EEG prolongée (VEP)

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KEYWORDS
Sleep deprived-EEG;
Long term video-EEG monitoring;
Ambulatory EEG;
Syndromic classification;

Summary Long-term EEG in adults includes three modalities: sleep deprived-EEG lasting 1 to 3 hours, 24 hours ambulatory-EEG and continuous prolonged video-EEG lasting from several hours to several days. The main indications of long-term EEG are: syndromic classification of epilepsy; search for interictal discharges when epilepsy is suspected or for the purpose of therapeutic evaluation; positive diagnosis of paroxysmal clinical events; and pre-surgical evaluation of drug-resistant epilepsy. Sleep deprived-EEG and ambulatory-EEG are indicated to detect interictal discharges in order to validate a syndromic classification of epilepsy when

Abbreviations: Amb-EEG, Ambulatory electroencephalogram or holter-EEG; ECG, Electrocardiogram; EEG, Electroencephalogram; EMG, Electromyogram; HV, Hyperventilation; IPS, Intermittent photic stimulation; LTVER, Longterm Video-EEG recording; SDE, Sleep-deprived EEG.

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Refractory epilepsy;
Paroxysmal clinical
events

standard EEG is negative. These exams can help in evaluating treatment efficacy, especially when clinical evaluation is difficult. Long-term video EEG is indicated for drug-resistant epilepsy, to analyze electro-clinical correlations in a pre-surgical evaluation context, and to refine a positive diagnosis when paroxysmal clinical events are frequent.
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MOTS CLÉS
EEG avec privation de sommeil ;
Vidéo-EEG ;
EEG ambulatoire ;
Épilepsie pharmacorésistante ;
Classification syndromique ;
Manifestations cliniques paroxystiques récurrentes

Résumé L'EEG prolongé chez l'adulte comprend trois modalités : l'EEG avec privation de sommeil réalisable sur une durée de 1 à 3 heures, l'EEG ambulatoire de 24 heures et l'enregistrement vidéo-EEG prolongé continu de quelques heures à plusieurs jours en milieu hospitalier. Les indications principales de l'EEG prolongé sont la classification syndromique de l'épilepsie, la recherche d'anomalies intercritiques en cas de suspicion d'épilepsie ou dans le cadre d'une évaluation thérapeutique, le diagnostic positif de manifestations cliniques paroxystiques et le bilan pré-chirurgical d'une épilepsie pharmacorésistante. L'EEG avec privation de sommeil et l'EEG ambulatoire sont indiqués pour la recherche d'anomalies intercritiques afin d'établir le diagnostic syndromique de l'épilepsie si l'EEG standard est négatif. Ces 2 examens peuvent aussi aider à l'évaluation thérapeutique en particulier lorsque l'évaluation clinique est difficile. La vidéo-EEG prolongée est indiquée en cas de pharmacorésistance pour l'évaluation des corrélations électro-cliniques dans le cadre d'un bilan pré-chirurgical de l'épilepsie, et lors de manifestations paroxystiques fréquentes pour obtenir un diagnostic positif.
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Summary of guidelines

Technical implementation of long-term EEG in adults

- Long-term EEG in adults should include a minimum of 21 EEG electrodes (Fp1, Fp2, F3, F4, F7, F8, T3, T4, T5, T6, C3, C4, P3, P4, O1, O2, Fz, Cz, Pz, one ground electrode and one reference electrode) and one ECG electrode.
- Long-term EEG recording in adults should be performed as continuous monitoring by a nurse or technician for LTVER (Non-consensual agreement, see the detailed chapter ''long-term EEG in adults'').
- Long-term EEG tests (SDE, LTVER, Amb-EEG) last at least one hour for a maximum period of 24 hours. If needed, the test can be repeated during several consecutive days. For LTVER, the simultaneous recording of good quality video is essential, with strict synchronization of the EEG signal and video.
- The objective of SDE is to promote EEG recording during sleep onset and sleep stages.
- Activation procedures (HV, IPS) recommended for standard EEG are performed during long-term EEG.
- Some additional options are proposed during long-term EEG:
  - to optimize the chances of recording an epileptic seizure, it is recommended to extend the hyperventilation procedure to at least 5 minutes, and if needed repeat this several times during long-term EEG;
  - addition of EMG electrodes on relevant muscle groups for the exploration of motor events;
  - addition of electrodes to explore the basal temporal area during pre-surgical LTVER in focal drug-resistant epilepsy.
- Medical intervention might be necessary during long-term EEG for diagnostic or therapeutic purposes (administration of antiepileptic drugs, specific stimulation procedures).

Indications for long-term EEG in adults

- Following a first epileptic seizure, when standard EEG and brain imaging have been performed and are normal, SDE is recommended to establish a syndromic classification.
- In the case of frequent clinical symptoms or confirmed drug-resistant epilepsy, LTVER is necessary to explore the electro-clinical correlations of seizure symptoms. It should last as long as necessary to collect all relevant data (EEG for the positive diagnosis of epileptic seizure).
- In the case of undetermined and recurrent stereotyped paroxysmal disorders, if their frequency is high enough, LTVER is recommended to establish a positive diagnosis and refine the nature of these disorders (EEG for the positive diagnosis of epileptic seizure).
- In other cases (rare disorders or symptoms), it is recommended to opt for SDE or Amb-EEG to search for interictal spikes.
- In treated epilepsy when circumstances render difficult the evaluation of the treatment efficacy (e.g. patient with several health conditions), Amb-EEG is useful to assess the therapeutic effectiveness using neurophysiological markers (therapeutic monitoring EEG).
- In treated epilepsy, when the management of epileptic seizures is not satisfactory, it is recommended to perform SDE to look for interictal spikes to potentially reassess the syndromic classification.
- In treated epilepsy, when the management of epileptic seizures is not satisfactory, LTVER is recommended after SDE to potentially reassess the diagnosis regarding the

nature of clinical events, when the latter are frequent enough.
- LTVER is indicated when surgical treatment is being considered in partial drug-resistant epilepsy. It should last as long as necessary in order to collect all relevant data (diagnostic EEG).

Long-term EEG reports in adults

In addition to the common information found in short-term EEG reports, the following elements should be included in the long-term EEG report:

- total recording duration;
- regarding SDE: eventual sleep onset, its duration and sleep stages obtained;
- temporal relationships between physiological and abnormal activities according to wakefulness and sleeping stages;
- when appropriate, indicate the presence of technical difficulties and recording limits encountered, whether permanent or temporary (e.g. artifacts preventing the interpretation of a portion of the Amb-EEG);
- regarding Amb-EEG: description of changes in the EEG retrospectively correlated to the notes taken by the patient or patient's family;
- regarding LTVER or SDE: EEG and clinical description of the events captured on video;
- determining the pathological nature of a reported activity should be discussed on the basis of validated published data;
- the analysis of the EEG and recorded electro-clinical events must be descriptive; only the conclusion should include comments of an interpretive nature, with regards to the clinical context;
- the conclusion being interpretative, the physician must use specific terms to clearly indicate the level of confidence given to the results provided: certain, probable, possible, doubtful, and excluded;
- the conclusion should answer the question raised by the physician who requested the EEG, using the terms published in the glossary of guidelines from the International League Against Epilepsy (ILAE) [2,3] (Non-consensual agreement, see Chapter ''proposals for writing EEG reports'').

Full-length guidelines

Definitions

Long-term EEG is a continuous recording of the EEG signal for at least 1 hour. Long-term EEG recording is based on specific needs highlighted in the EEG request provided by the physician. Long-term EEG can range from 1 hour to 24 hours and can possibly be prolonged for several days or weeks, in order to establish a diagnosis or in the context of pre-surgical monitoring. It is usually coupled with video recording (long-term video EEG recording, LTVER), can be performed in ambulatory mode (ambulatory EEG or Holter-EEG, Amb-EEG), or require specific conditions (sleep deprived EEG, LTSDE). Due to the long-term nature of the recording it is possible to carry out medical, therapeutic or diagnostic procedures during the EEG in order to appreciate the induced changes on either the behavior or the EEG trace.

The separation of these three procedures (LTVER, LTSDE and Amb-EEG) can be debated and might seem artificial: their differences are restricted to:

- defining prerequisite conditions prior to the EEG recording (LTSDE);
- video recording associated with EEG (LTVER);
- or ambulatory EEG recording to maintain the patient's autonomy (Amb-EEG).

As a matter of fact, in some circumstances, the three different recording modes can be combined: LTVER monitoring after programmed sleep deprivation, to promote interictal discharges or seizures, then performed in ambulatory mode to continue the recording after lab hours. There are however some nuances between these three modes, based on the different indications, albeit with a few overlaps (Table 1).

Finally, studies in the literature have often treated these three procedures separately, sometimes even comparing them. We chose to analyze these three different modes separately rather than considering long-term EEG as a separate entity with additional procedures (+ video, + sleep deprivation, + ambulatory mode).

Methods

A literature analysis regarding recording methods, indications and clinical value, was published (last updated January 11, 2014), based on study data available on PubMed, Web of Science, using the following keywords: ''*Video-EEG*'', ''*Ambulatory EEG*'', ''*sleep-deprived EEG*'', crossed with ''*guidelines*'', ''*diagnostic value*'', ''*evaluation*''. Articles in French and English were considered. Articles were included based on their topic relevance and classified into ''recommendations'', ''review article'', ''original article''. Raw data, conclusion and recommendations proposed were the object of a systematic analysis; procedures and indications were classified by the reading group according to their level of recommendation.

This work focused on data available, except for studies focusing on hypnology. The evaluations of polysomnography procedures were not analyzed here. The proposed recommendations do not concern clinical situations related to sleep pathologies.

Sleep deprived EEG (SDE) in adults

In 1947 Gibbs and Gibbs introduced the notion of sleep as a stimulation procedure in epileptic patients, who had a normal initial standard EEG, in order to promote the onset of specific abnormalities. The increase of epileptic discharges during sleep was then validated in several other studies [4,31] stressing the positive role of the availability of a sleep trace during the EEG recording. Furthermore, sleep, wakefulness and epilepsy are closely interconnected not only for the onset of seizures but also in terms of modulation of interictal activities [27]. Finally, the presence of epileptic discharges during sleep in seizure-free epileptic patients

Table 1 Differentiation of the three long-term EEG modes according to the main (+++) or secondary (+) indications.

	Recording of seizures for topographic diagnosis	Diagnosis of paroxysmal clinical events (diagnosis of epileptic seizures)	Diagnosis of specific EEG abnormalities (syndromic classification)	Evaluation, monitoring and quantification of EEG abnormalities
Video-EEG (LTVER)	+++	+++	+	+
EEG after sleep deprivation (LTSDE)	+	+	+++	+
Ambulatory EEG (Amb-EEG)	+	+	+	+++

Table 2 for details of the studies evaluating the indications.

could predict the risk of recurrence after the interruption of antiepileptic treatments [31].

Since it is relatively rare to obtain spontaneous sleep during daytime EEG recording, sleep deprivation is the first method of choice to obtain sleep during EEG acquisition, or at minimum, an intermediate state of vigilance, such as drowsiness or falling asleep. The efficacy of this method remains to be validated and has not yet been thoroughly assessed. However, it is most likely that sleep deprivation is more relevant than spontaneous sleep recording [50].

As a matter of fact, more abnormalities arise during transition phases and after having waken up [38]. There is a noticeable increase of epileptic abnormalities during the awakening phases in sleep deprived patients [81,99] thus suggesting that sleep deprivation might influence EEG recording independently of having achieved the different sleep stages [67,103]. Studies in healthy controls measured the cortical excitability with and without sleep deprivation and validated the specific role of sleep deprivation on cortical excitability increase [32]. The sensitivity of various EEG protocols (standard EEG, EEG after sleep deprivation and medication-induced sleep EEG recording) was studied on a population of young adults presenting with suspected epilepsy, results showing a higher sensitivity for sleep-deprived EEG [73]. However, other studies reported that sleep deprivation did not have a greater stimulating effect than spontaneous sleep for generalized and partial epilepsy alike [78]. It is in fact the duration of the recording that increases the frequency of the abnormalities: the longer the recording, the higher the number of abnormalities detected. In fact there is a direct link between recording duration and probability of collecting interictal abnormalities [57]. One should note however, that the effectiveness of nap EEG is at least similar to nighttime sleep EEG since epileptic spikes are more frequent in slow-wave sleep and commonly encountered when falling asleep or at the beginning of the sleep cycle [71,132]. Another study, reported that the activation of abnormalities during long-term EEG was not influenced by recording duration after sleep deprivation or by the duration of the Stage 2 of the sleep cycle [50].

In spite of more than 60 years of practice, the relevance and effectiveness of this investigation remains debated, along with technical modalities and indications. Data from the literature account for the disparity of the procedures used. It is quite difficult to evaluate the respective contribution of independent or associated factors involved in the activating effect. These factors are sleep deprivation, sleep recording, long-term recording, vigilance fluctuations, onset of spontaneous or triggered awakening, repeated nature of the routine stimulation procedure (HPV, IPS) and increased sensitivity to light after sleep deprivation [123].

Definition

EEG after sleep deprivation and long-term EEG (duration comprised between 1 and 3 hours), performed in the specified conditions of sleep deprivation, are designed to promote variations in spontaneous vigilance and, when appropriate, record brain rhythms during sleep. Sleep EEG recording (random variable) during long-term EEG cannot be a prerequisite, but it should be an objective. Sleep could be achieved in the morning after sleep deprivation, or at naptime. Video is recommended, but not mandatory, especially when the goal of the examination is to determine neurophysiological markers of an epileptic syndrome (interictal activity) after normal routine EEG.

Recording technique

Duration of the sleep deprivation procedure. Recommendations from the International League Against Epilepsy [48,124] emphasize that adult patients should abstain from sleep the night prior to the recording. However, no studies in the literature have compared in a prospective manner the impact of partial sleep deprivation (usually reduction from 30 to 50% of the patient's usual sleeping time, most often, 4 hours of sleep during the night) vs. complete sleep deprivation (no sleep during the night prior to the recording). The duration of sleep deprivation varies greatly according to the different studies. Some authors recommend no sleep the night prior to the recording even though partial sleep deprivation seems to yield the same efficacy [40,58,69]. The selective effect of sleep deprivation according to sleep stages has been assessed in a very small number of studies and showed that slow-wave sleep deprivation only activates partial epileptiform discharges, whereas REM-sleep stage (paradoxical sleep) triggers generalized and partial abnormalities [15].

Risks related to sleep deprivation. Sleep deprivation is a somewhat cumbersome procedure for patients, their family and healthcare personnel, and seems to yield a risk of

epileptic seizures in 3 to 5% of non-epileptic patients [30]. As a matter of fact, it is preferable to reserve this sleep deprivation for patients with clinically suspected epilepsy when routine EEG recordings are normal. In some situations, partial sleep deprivation can be proposed (for example waking up the patient earlier in the morning), in order to induce sleep and sleepiness only. Combined with other precautions (no stimulating beverages, recording taking place in the afternoon after a full meal), it can ensure the presence of sufficient sleep stages during the recording [78].

The risk of seizure onset after isolated sleep deprivation is theoretical and depends on the epileptic syndrome. If the activation of epileptic abnormalities in juvenile myoclonic epilepsy is common after sleep deprivation [116], the latter has less influence on seizure frequency in patients suffering from drug-resistant partial epilepsy, under continuous monitoring in a hospital setting [77].

Sleep deprivation is generally done at home, but some high-risk situations related to the patient's epileptic syndrome (where the risk of occurrence of generalized tonic-clonic seizures is elevated), can justify performing the sleep deprivation in a hospital setting in order to monitor the patient.

Recording duration. The activation of epileptic abnormalities is not influenced by the total duration of EEG recording after sleep deprivation or by the duration of light slow-wave sleep [78].

Since the objective is to obtain sleep, nap conditions are set-up (in the morning or afternoon). Ideally, the recording should include a waking state and sleepiness stages and if possible sleep stages 2 and 3. The EEG recording should include a montage allowing the detection of the usual sleep figures (mainly median line electrodes Fz, Cz, Pz). It can be associated with other polygraphic channels: electro-oculogram, (chin EMG, ECG) to analyze sleep stages (slow-wave sleep, REM sleep) [48].

The recording duration must be adapted to the type of data being researched. For example, recording interictal activities for syndromic diagnosis, recording activities in the transition phase between sleep and wakefulness (which includes falling asleep, light slow-wave sleep stage and triggering of the awakening process) followed by IPS and HPV all seem sufficient and can be done during a half-day period (3 hours) [58]. However when the objective is to record clinical events, the duration can be lengthened and physicians can recommend long-term EEG.

When should sleep-deprivation EEG be performed?

The acquisition of relevant data is increased if the EEG is performed in the 3 days following the patient's first seizure [52]. Recording a nap from 1 to 3pm after a partial 3-hours sleep deprivation the night before is often quite efficient [95]. There is no difference between morning or afternoon nap recording with regards to the onset of sleep and subsequently induced EEG abnormalities [58].

Alternative solutions when sleep deprivation has failed

When sleep deprivation fails (e.g. anxious patients, patients requiring very little sleep, autistic or intellectually impaired patients), or when sleep deprivation is difficult to implement (e.g. encephalopathy, patients in an institution), certain drugs can be employed to facilitate naptime sleep. This method seems to be as effective as sleep deprivation to obtain naptime sleep [123]. However, using benzodiazepines to promote sleep is not recommended since it can reduce the sensitivity of detecting epileptic abnormalities [99]. Melatonin when used to induce naps in children or patients with intellectual disability does not alter sleep structure or frequency of epileptic abnormalities [109]. It does not have noteworthy adverse events and seems to be as effective as sleep deprivation in children. It is also better accepted by the patients' families [127]. No study has focused on using melatonin to obtain naptime-condition EEG recording in non-cooperative adults, autistic or intellectually disabled patients. Other medicines have been suggested or are sometimes used (Amitriptyline®, Hydroxyzine®); however no studies have validated these drugs in adults. Neuroleptic sedation drugs, outside of exceptional circumstances, should be avoided, and when used the physician should clearly justify the choice in the EEG request.

Interpretation

The objective of this examination is to highlight epileptic activities such as generalized or focal spike, slow wave and spike-and-wave activity according to the epileptic syndrome. This procedure is expected to promote EEG abnormalities typical of an epileptic syndrome, due to the impact of sleep deprivation on the spontaneous level of alertness of the subjects. In this context, this procedure is specifically indicated to refine the diagnosis of the epilepsy syndrome (Table 1).

Indications

The most common indication is the exploration of seizures suspected to be of epileptic origin, when the standard EEG is normal. It contributes to yielding additional useful data (neurophysiological markers: interictal EEG activities) for the classification of epileptic syndromes [98]. It can also be used for the monitoring of antiepileptic drug withdrawal and therapeutic adaptations. The fortuitous acquisition of a clinical event can happen, yet it is rarely the main objective of the procedure (Table 1). Table 2 lists all the references found in the literature pertaining to the diagnostic contribution of the different long-term EEG procedures.

Emergency situation context

There are no emergency indications. Performing early LTSDE in a young adult who has had a first clinically confirmed epileptic seizure can guide the physician and help estimate the risk of recurrence; it could possibly justify the need for antiepileptic treatment and guide its management in light of the syndromic diagnosis.

Cost

EEG with sleep deprivation is an easy and inexpensive method to yield EEG abnormalities [73]. However, it requires the availability of trained personnel due to the technical specificities and long-term monitoring when compared to standard EEG. In spite of this constraint and taking into account the theoretical risk of triggering generalized seizures, this technique remains a simple cost-effective way to achieve positive diagnostic contributions [22]. In terms of

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Table 2 Original studies assessing the diagnostic contribution long-term EEG procedures.

Reference	*n*	Population characteristics	Analytic methodology	Recording procedure	Mean duration in days (range)	Diagnostic category (%)	Interictal events (%)	Diagnostic contribution	Comparison	Notes
Abubakr and Wambacq, 2005 [1]	58	Tertiary center, patients > 60 years	Retrospective	LTVER 24/24	3.2 (2—9)	A57, C36, D7	26 (45%) PNE, 23 (39%) ES[a], 6 (10%) PNES	100%	Absent	
Alving and Beznicky, 2009 [3]	221 (234 admissions)	Tertiary center, patients who already had an EEG, LTSDE, LTVER < 4 h	Retrospective	LTVER 24/24	2.4 and 2.5 (3.5 for Cc)	A53, C41 (Cc24), D6	195 (83%) of admissions	78% (17% before monitoring)	Absent	Inclusion of sleep disorders. AED withdrawal in 45 cases
Attarian et al., 2003 [7]	27	Tertiary center, patients with VNS or awaiting VNS implantation	Retrospective	LTVER	NA	Cc100	NA	2 dg revisions (PNES) and 2 revisions of VNS indication	Absent	
Baheti et al., 2011 [9]	148	Tertiary center, patients > 45 years	Retrospective	LTVER > 8 h	2.9 (0.5—10)	A 21 B 20.2 Cc 58.8	86.5% (74.3% ES, 9.5% PNES, 12.8% ES + PNES) 87.8% IA	94,8% C (dg or dg validation) 93% A (dg or dg validation)	Absent	
Benbadis et al., 2004 [14]	251	Tertiary center	Retrospective	LTVER	2.8 (1—7)	A, B, C, Cc	77.3% (42% ES, 24% PNES, 2,4% PNE)	85% dg contribution	Absent	
Bhatia et al., 1996 [16]	50	Tertiary center, patients with suspicion of PNES	Retrospective	''Day'' LTVER with placebo injection	NA	A 100	60%[a]	70% dg validation and 50% dg	Absent	Children were included
Boon et al., 1994 [19]	100	Tertiary center	Retrospective	LTVER 24/7	3.5 (2—15)	A 37, C 63	63 (63%)	63%	Absent	
Cambier et al., 2001 [21]	84	Tertiary center, patients with hippocampal atrophy and drug-resistant epilepsy	Retrospective	LTVER	NA	Cc 100	100%	(lateralization) 76.4% concordance, 3.5% discordance, 19.9% no decision possible. No impact on surgical outcomes	Surgical outcomes	

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Table 2 (*Continued*)

Reference	*n*	Population characteristics	Analytic methodology	Recording procedure	Mean duration in days (range)	Diagnostic category (%)	Interictal events (%)	Diagnostic contribution	Comparison	Notes
Chemmanam et al., 2009 [25]	143	Tertiary center	Prospective	LTVER > 3 h	2.5 (0.16–14)	A 7.7, B 21, Cc 71.3	95.1% 88% IA	Dg contribution 93.2%, dg revision 39.9%	Absent	Developing countries, children were included, AED withdrawal 80.4%
Dash et al., 2012 [29]	101	Tertiary center	Retrospective	Amb-EEG	1.3 (0.6–4)	A 78.2, C 12.9, D 9.9	30.8% PNE et PNES	71%	Absent	
Elgavish and Cabaniss, 2011 [39]	87	Tertiary centers, patients recruited after negative primary LTVER	Retrospective	LTVER	NA	A 100	NA	55.2% after one negative LTVER 40% after two negative LTVERs (2/5)	Absent	
Faulkner et al., 2012 [45]	180	Tertiary center	Retrospective	Amb-EEG	4	B 100	100% IA (28 GIA, 72 FIA)	IA recorded in 44% of cases in the first 4 h, 58% in the first 8 h, 85%, in the first 24 h and 95% in the first 48 h. Mean recording duration: 316 min	Absent	Children were included
Faulkner et al., 2012 [46]	324	Tertiary center	Retrospective	Amb-EEG	4–5	A 60, B 30, D 10	52%	68% dg contribution, 22% dg revision	Absent	
Friedman and Hirsch, 2009 [51]	248	Tertiary center	Retrospective	LTVER	5 (1–55)	B, C, Cc	67%	Median durationbefore ES: 2 days, Median duration before NE: 1 day	Absent	
Ghougassian et al., 2004 [54]	131	Tertiary center	Retrospective	LTVER	5,6 (1–13)	AB 69, Cc 30	69% (43% ES, 24% PNES, 2% ES + PNES)	58% of dg revision	Absent	AED withdrawal 88%

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Table 2 (*Continued*)

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Giorgi et al., 2013 [55]	210	Tertiary center, 'de novo' patients	Retrospective	LTSDE	2.5 h	A, B	41.2% IA	41.2% dg contribution after routine standard EEG	Absent	
Gueirrero et al., 2002 [56]	73 (91 recordings)	Tertiary center, drug-resistant temporal epilepsy	Prospective	LTVER 24/7 vs. daytime LTVER	NA	Cc	85% in the 24/7 group 24/24, 61% in the daytime group	No significant difference between both groups	Two LTVER modalities	AED withdrawal only in the 24/7 group
Heers et al., 2010 [61]	63	Tertiary center	Retrospective	LTSDE	30—40 min	A, B	51% IA in LTSDE, 60% in magnetoen-cephalography		MEG	
Keranen et al., 2002 [65]	36	Tertiary center, age > 60 years	Retrospective	LTVER	4.5 h (1—20 h)	A 81, C 19	44%	44% dg contribution	Absent	
Kipervasser and Neufeld, 2007 [66]	16	Tertiary center, age > 60 years	Retrospective	LTVER	6,9 (1—18)	A, C, Cc	100% (43% PNES, 36% ES, 2 inconclusive, 1 ES + PNES)	88% dg contribution	Absent	
Lancman et al., 1996 [70]	20	Tertiary center, age > 60 years	Retrospective	LTVER	4 (1—10)	A, C	55%	55% dg contribution, 20% additional diagnostic to the neurologist opinion	Absent	
Liporace et al., 1998 [74]	46	Tertiary center	Retrospective	LTSDE vs. Amb-EEG	LTSDE30—60 min, Amb-EEG 24 h	A, C	15% ES (Amb-EEG) vs. 0% (LTSDE) 30% IA (Amb-EEG) vs. 24% IA (LTSDE)	Similar increase in dg contribution after routine EEG (IA) but 15% ES in Amb-EEG	Comparison LTSDE and Amb-EEG	
Martin et al., 1998 [80]	20	Tertiary center, PNES dg via LTVER	Retrospective	LTVER	3.1 (1—8)	A	100% (recruitment criteria)	84% decrease in medical costs after PNES dg	Absent	Cost-effectiveness economic study
McBride et al., 2002 [82]	94 (99 admissions)	Tertiary center, age > 60 years	Retrospective	LTVER	3.8 (1—14)	A 71, C 20, Cc6, D 3	75% (46% ES, 13%, PNES, 14% PNE)	75% dg contribution	Absent	

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Table 2 (*Continued*)

Reference	*n*	Population characteristics	Analytic methodology	Recording procedure	Mean duration in days (range)	Diagnostic category (%)	Interictal events (%)	Diagnostic contribution	Comparison	Notes
McGonigal et al., 2002 [83]	30	Tertiary center, suspicion of PNES	Prospective Randomized	Short-term VER	NA	A	66% with suggestion, 33% without suggestion		With or without suggestion	> 16 years
McGonigal et al., 2004 [84]	143	Tertiary center	Retrospective	Short-term VER	40—50 min	A	50.3%	50% dg contribution	Absent	Children were included
Robinson et al., 2011 [102]	43	Tertiary center, when the first LTVER was negative	Retrospective	LTVER	NA	A	42%	42% dg contribution when the first LTVER was negative	Absent	
Varela et coll. 2007 [122]	52	Tertiary center, suspicion of PNES	Retrospective	Short-term VER with suggestion	NA	A	67%	67% dg contribution	Absent	

Studies on pediatric population or descriptive studies (case series) were not considered for this table. Synthetic articles were not retained. Only original studies pertaining to diagnostic contribution were included in the table. Diagnostic categories: A: seizure diagnosis: nature of the seizure is unknown prior to the procedure; B: syndromic classification: the epileptic nature of the seizure is strongly suspected, but syndrome classification is needed for therapeutic purposes; C: topographic diagnosis: epileptic nature of the seizure has been established, the recording aimed at evaluate topographic locations. Cc: specifically for pre-surgical evaluation; D: others: therapeutic adjustment, monitoring the frequency of epileptic seizures. NA: not available; PNES: psychogenic non-epileptic seizure; PNE: physiological non-epileptic seizure; ES: epileptic seizure; dg: diagnostic; IA: interictal activity; GIA: generalized interictal activity, FIA: focal interictal activity; AED: antiepileptic drugs.

[a] Contradictory data in the results.

the current situation in France, the low financial retribution of this exam could lead in a few years to an under-evaluated cost compared to its real cost, thus challenging its future, especially in the private practice sector.

Long-term ambulatory EEG (AMB-EEG/HOLTER-EEG)

A clinical diagnosis of epilepsy is incorrectly made in more than 30% of patients [72,111]. Differential diagnosis from other conditions is essential owing to the main pathologies wrongly diagnosed as epilepsy: syncope and psychogenic non-epileptic seizures. Standard 20-minute EEG recording yields interictal epileptic abnormalities in 30 to 50% of cases. Repeating this examination could increase the rate of abnormalities to 60-70% [36]. Studies have reported that in 10% of epileptic patients, interictal abnormalities are not revealed via the various EEG modalities [17]. As a matter of fact, the International League Against Epilepsy [124] recommends long-term EEG monitoring when the diagnosis of epilepsy is uncertain, to classify the epileptic syndrome, quantify seizures, establish the circadian pattern (daytime or nighttime) and finally to document electroclinical semiology prior to surgical management. Such long-term monitoring can be done at the hospital or on an ambulatory basis. Older studies [20,37] using long-term EEG with 4 or 8 electrodes have reported the effectiveness and usefulness of these ambulatory EEG recordings. The most recent studies on recordings with 16 electrodes, because of improvement in the EEG technology, have validated the relevance of these long-term recordings.

Definition and recording technique

Amb-EEG is defined as an ambulatory recording of the electrical activity of the brain for a minimum of 24 hours where patients can maintain their regular activities of daily living at home or at work.

After skin abrasion, a minimum of 16 electrodes is fixed using water-based paste (EC2™) and the set-up maintained by a net. The electrodes are connected to a portable recorder carried over the shoulder.

An ECG channel is required to detect cardiac conduction disorders that could be associated with clinical events, and in order to correlate ECG artifacts on the EEG trace. A study of 861 patients with neurological disorders showed that 14% of them presented with interictal arrhythmia and 4% with neurological symptoms related to cardiac disorders [92].

The presence of an ''event'' button on the device is strongly recommended for patients and their family. It allows transcription of an ''event'' on the EEG trace when clinical events occur. Patients and/or family members are asked to keep a diary of their activities performed during the recording period. The timing and description of these clinical events should also be noted in the diary.

Data are recorded on a memory stick, with a minimum capacity of 24 hours of EEG recording at the sampling frequency of 256 Hz and resolution of 12 bits for 32 electrodes. The recorder is fitted with a rechargeable battery or batteries enabling at least 24 hours of EEG recording. A control of the impedances (ideally < 5 ohms), calibration and quality of the signal must be verified before the patient leaves with the Amb-EEG device and checked again every 24 hours if the recording is to be continued.

Indications for long-term ambulatory EEG recording

Validating the clinical diagnosis of epilepsy (detection, characteristic and quantification of paroxysmal events). Studies pertaining to the diagnostic contribution of long-term ambulatory EEG (Amb-EEG) have shown that seizures were recorded in 6 to 15% of cases. The performance of Amb-EEG depends on several factors:

- number of recording channels: the performance of the Amb-EEG is better with the 16-channel system assisted by seizure detection features than with the older 4-8-channel systems without seizure detection [87,88];
- recording time: studies evaluating a mean duration of 28 hours of recording reported 8.5% of seizure detection in a cohort of 502 patients [120] and 11.9% [88] in a cohort of 344 patients. This rate went up to 20% in 324 patients in a study where the mean EEG recording duration was 96 hours [45,46];
- time when the recording is performed: Amb-EEG performed in the 48 hours following a seizure, increases the diagnostic contribution by 68% [118].

Another major feature of Amb-EEG is the possibility of recording a natural sleep cycle and thus evaluating the circadian rhythm of seizures, especially for those occurring preferentially during nighttime sleep [113]. Sleep conditions can optimize the search for interictal abnormalities and help to refine the syndromic diagnosis of epilepsy. In generalized epilepsy, the frequency of interictal abnormalities is increased at the beginning of sleep (falling asleep stage) and is higher during light sleep than when the patient is awake. However, REM sleep slows down or even stops the onset of epileptiform discharges. Transition phases and arousals triggered during the sleeping period represent major activating factors in the production of interictal abnormalities. In generalized, non-convulsive epilepsy, absences and discharges are often observed when falling asleep, during light sleep or when the patient wakes up. In partial epilepsy, interictal abnormalities are more common during slow-wave sleep. Usually, diffuse abnormalities are observed. Generally, during REM sleep (paradoxical sleep), the frequency and amplitude of the abnormalities tend to decrease; however this particular sleep stage helps refine their precise focal nature [108].

Finally, in patients with drug-resistant epilepsy, Amb-EEG can be used to determine the epileptogenic zone (EZ) of the brain for pre-surgical evaluation [24,112]. It should be noted however that both of these cited studies were retrospective, came from the same center and only concerned a small number of patients (7 for the first one and a case report for the second one). One of the main drawbacks of Amb-EEG lies in the absence of the physician's evaluation when the patient experiences a seizure. For all these reasons, long-term video EEG must remain the gold standard for presurgical evaluation of drug-resistant epilepsy.

Evaluation of non-epileptic events. The frequency of non-epileptic seizures is estimated to be 20% in epilepsy reference centers and 5 to 20% in the general population.

In the epileptic population, epileptic seizures are frequently associated with non-epileptic seizures (10 to 60%). Thus, Amb-EEG can represent a useful tool to identify non-epileptic paroxysmal events. However, the absence of video recording is a problem since it cannot refine the stereotypic nature of the phenomena. Furthermore, it is possible that scalp EEG cannot record epileptiform discharges arising from certain brain regions such as the mesial part of frontal lobe [64]; thus in some situations and in the absence of video recording the doubt might linger. Finally, during paroxysmal motor events, some muscular artifacts render the EEG interpretation difficult or even impossible. Video-EEG remains the gold standard examination for evaluating non-epileptic seizures.

Evaluation of interictal paroxysmal activity. In patients with suspected epilepsy, when standard EEG and sleep-deprived EEG (SDE) examinations are normal, Amb-EEG can highlight the interictal paroxysmal activity in 12—25% of cases.

One study has compared the diagnostic contribution of sleep-deprived EEG vs. 24-hours Amb-EEG recording in 46 patients with suspected epilepsy. SDE highlighted interictal abnormalities in 24% of cases, whereas Amb-EEG revealed abnormalities in 33% of cases. Furthermore, only the long-term recording was able to record seizures in 15% of cases [74]. Other studies showed a similar detection rate of interictal abnormalities. Morris et al. [88] found interictal abnormalities in 25.9% of their 344 patients with a mean recording time of 32 hours.

Treatment evaluation: treatment response and stopping antiepileptic treatment. Commonly, treatment efficacy is evaluated according to the seizure frequency reported by patients. However, studies have shown that this criterion is not reliable since the number of unidentified seizures is usually quite high. Blum et al. [18] showed that 63% of seizures recorded in an epilepsy monitoring unit were not identified by the patient. Liporace et al. [74] showed that out of 21 seizures recorded, only 10 were reported by patients. Tatum et al. [120] also evaluated the frequency of non-reported seizures on 552 recordings. 47 partial seizures (8.5%) were detected including 18 (38.3%) that were not identified by the patient.

Amb-EEG should be proposed as a more reliable tool and objective method for assessing the effectiveness of the patient's antiepileptic treatment [117]. Furthermore, detecting non-identified seizures can permit to adapt the patient's care management especially in evaluating the patient's driving ability [44].

When the patient has been seizure-free for a long period of time, usually between 3 to 5 years, and in the absence of abnormalities on standard EEG, the decision to stop AED can be discussed. The EEG contribution in predicting successful treatment withdrawal remains debated. Very few studies have evaluated the relevance of long-term EEG. A first study on a cohort of 15 patients with learning disabilities, and a median 10-year seizure-free period, found that the Amb-EEG had detected interictal abnormalities in the 6 patients who had seizures after treatment withdrawal. These results were backed up by a Chinese study that assessed the relevance of Amb-EEG in predicting seizure recurrence after medication withdrawal. This study showed that a longer time period before the disappearance of epileptic abnormalities (i.e. > 3 years) on the Amb-EEG was correlated with a higher seizure recurrence rate [130].

No study has evaluated the relevance of Amb-EEG vs. standard EEG for the evaluation of AED withdrawal. However, one study showed that the Amb-EEG remained abnormal in 41.1% of patients who were seizure-free for a 3 to 5-year period [126]. However, the authors did not evaluate patients' outcomes after treatment withdrawal.

What is the ideal recording duration?

Only one study has studied the latency to first interictal epileptiform discharge. Median latency to a first interictal event is 316 minutes. Interictal abnormalities were recorded in 44% of patients within the first 4 hours, 58% within the first 8 hours, 85% within the first 24 hours and 95% within the first 48 hours [45,46].

Regarding epileptic seizures, latency to first seizure is 51% in the first 24 hours, 70% in the first 48 hours, 79% in the first 72 hours and 100% in the first 96 hours. For non-epileptic seizures latency is shorter, 60% in the first 24 hours, 82% in the first 48 hours, 92% in the first 72 hours and 100% in the first 96 hours [45,46].

In another study, the same authors showed that 48 hours of recording seemed satisfactory for electro-clinical classification of the recorded interictal abnormalities [45].

Conclusion

The value of EEG in the diagnosis and classification of epilepsy has been largely validated. Amb-EEG has a greater value than routine EEG since it contributes to diagnostic validation in 72% of cases [29]. In 51% of cases, it induces changes in the medical care management of these patients either by correcting the initial diagnosis or by modifying the initial epileptic syndrome classification into focal or generalized. Another major relevance of EEG is its ability to record spontaneous sleep (or natural sleep) and evaluate the circadian rhythm of interictal abnormalities, thus contributing to the syndromic diagnosis.

Compared to long-term recording at the hospital, the main advantage of Amb-EEG is its lower cost [50], the possibility of recording patients in their living environment and being able to trigger seizures when these triggering factors have been identified. Main drawbacks are: technical issues, especially artifacts induced by movements and muscle activity electrode artifacts (poor impedance), rendering the interpretation of the EEG quite difficult; lack of evaluation of the patient by a physician during ictal and postictal periods. Table 2 lists all the studies that focused on diagnostic contribution of the different long-term EEG procedures.

Long-term video-EEG recording (LTVER)

Definition

Video-EEG is the simultaneous and synchronized recording of the EEG and behavior of the patient by the means of video. Historically introduced in France in the fifties and sixties [54,62], these techniques were further developed in the eighties through technical advances and the possibility of synchronizing video images and EEG recording.

Long-term video EEG (LTVER) associates EEG recording and videotaping for at least one hour. It can be extended

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to 24 hours (continuous monitoring) [42] and repeated several days in a row. Coupling video to the simultaneous and synchronized recording of EEG activity can establish electro-clinical correlations by associating the clinical symptoms exhibited by the patient and concomitant EEG aspects. This is why LTVER is usually dedicated to recording relevant paroxysmal clinical events (Table 1), in order to diagnose:

- the nature of the episode (e.g. epileptic seizure, psychogenic non-epileptic seizure, syncope);
- electro-clinical correlations of an epileptic seizure before surgical management of epilepsy.

Technique

Electrodes and signal acquisition. For proper EEG signal acquisition surface electrodes must be sturdily positioned to enable long-term recordings. Collodion is no longer used and has been replaced by EC2™-type paste, [42], preferable to head cap wear. There must be at least 19 electrodes positioned according to the 10-20 system. According to the indication, electrodes exploring basal and anterior temporal regions (FT9, TP9 and FT10, TP10) may be added. The signal acquisition is carried out in referential montage. Data are acquired digitally after amplification. The digitized EEG signal allows reconstruction of the different montages and allows the possibility of changing the reference [23].

EEG recording is coupled to ECG and potentially to other parameters, especially EMG recording (electrodes positioned above the deltoid or tibialis anterior muscles, or others depending on the semiology described). In case of nocturnal symptoms an electro-oculogram and pulse oximetry can be requested. SaO_2 oxygen saturation acquisition is recommended for all long-term video EEG recordings in the framework of pre-surgical evaluation. In fact, these patients, who may be partially weaned from their treatment in order to trigger seizures, carry a higher risk of sudden unexpected death in epilepsy (SUDEP). In this case, it is recommended to have an oxygen desaturation alarm to warn healthcare teams of the seizure.

Video acquisition relies on cameras positioned in the patient's room. One or two cameras are usually used (giving the possibility of obtaining a dual image with a general view of the room and close-up of the patient's face). Usually an infrared camera is needed for nighttime recording.

Data are stored in a digital format.

Safety and human resources. The monitoring of LTVER patients requires close interaction between the healthcare staff (EEG technicians, nurses, physicians) and patients. The evaluation of electro-clinical correlations must be based on a precise interview as well as examination of the patient adapted to the type of events recorded: e.g. test the preservation of consciousness with the patient, language (comprehension and verbal expression), evaluate subjective symptoms experienced by the patient, and perform muscle testing. Healthcare teams must be experienced, trained and with a sufficient number of personnel near the patient's bedside [10].

A medical presence is necessary according to the type of event recorded, in order to perform stimulation (suggestion, placebo injection for non-epileptic seizures) or therapeutic techniques (e.g. benzodiazepine injection in case of non-convulsive status epilepticus, curare in the ICU for disruptive muscle artifacts). The presence of severe psychiatric or behavioral disorders associated with epilepsy justifies an intensive clinical monitoring [28]. Recommendations were published for the safety of some type of LTVER monitoring (treatment weaning) [115].

LTVER indications

Most authors [4,41] and the neurophysiology sub-committee from the International League Against Epilepsy retained four main indications underlined in [54,124]:

- positive diagnosis of recurrent paroxysmal events: differential diagnosis between epileptic seizures and non-epileptic seizures, especially psychogenic non-epileptic seizures, abnormal movements during sleep, etc.
- syndromic classification of epilepsy: by detecting, defining and quantifying interictal abnormalities in patients in whom the type of seizures or epileptic syndrome have not yet been defined. This indication is mainly explored via LTSDE;
- quantification of ictal and interictal seizures according to circadian variations (daytime and nighttime, sleep recording) and measurement of the therapeutic effect on these variables;
- localisation (study of electro-clinical correlations) of the seizures, in the framework of pre-surgical evaluation of partial drug-resistant epilepsies.

The neurophysiology sub-committee of the International League Against Epilepsy, reviewed by Vélis et al. [124], also emphasized the indication of LTVER for documenting specific sleep-related abnormalities (such as the continuous spike and waves syndrome during slow sleep) and monitoring in the ICU (detection of sub-clinical seizures or status epilepticus, control of status epilepticus treatment efficacy). Table 2 lists all studies evaluating diagnostic contribution in the various long-term EEG procedures.

Duration of Video-EEG monitoring

By definition, LTVER lasts from one to 24 hours. It can be repeated for as many days as needed. In the framework of pre-surgical monitoring, the common duration is 1—2 weeks but can be shortened, according to the collection of relevant electro-clinical events. The mean duration required for relevant clinical events varies from 4.9 to 7.6 days [23,26,41,47] according to the population studied, etiology and management of the antiepileptic treatment (rapid treatment withdrawal) [124].

The mean duration for recording a first clinical event is 2 to 3 days; 35% of cases require 3 days or more and 7% more than a week [51,75,125]. The duration of the recording is generally longer for pre-surgical exploration (3.5 days in average) vs. 2.4 days and 2.3 days respectively in the context of diagnostic purposes and syndromic evaluation [3].

Regarding psychogenic non-epileptic seizures, the delay in recording an event is generally significantly shorter, often inferior to 24 hours, even more so when the clinical event is characterized by hypermotor or akinetic symptoms [96]. Some authors found no latency difference for a first event

between epileptic seizures and psychogenic non-epileptic seizures [75,129].

Promoting factors

Several factors can promote the recording of paroxysmal events. According to the clinical situation, it can be recommended to perform sleep deprivation, hyperventilation procedure, intermittent photic stimulation or specific seizure-triggering movements in reflex epilepsy [124]. Sleep deprivation as a factor promoting the onset of seizures during long-term EEG recording has been debated. As a matter of fact, Malow et al., in a controlled study, showed that acute sleep deprivation did not impact on complex partial seizure frequency [77].

Progressive and carefully conducted antiepileptic treatment withdrawal can reduce the total duration of video-EEG monitoring [23]. AED withdrawal can increase the frequency of complications, especially series of seizures and status epilepticus [104] yet without significantly increasing the rate of severe complications [34]. Moien-Afshari et al. [86] showed that a faster treatment withdrawal over a 24-hour period is also possible, to reduce recording duration and thus EEG cost without increasing the risk of complications (only 8% of patients experienced minor complications) and with good diagnostic contribution, giving a diagnostic answer in 88% of patients.

Hypnosis, and other behavioral techniques including seizure provocation by suggestion techniques were reported as effective in triggering psychogenic non-epileptic seizures [11,54].

Impact of long-term video-EEG compared to standard EEG

Around 50 to 60% of epileptic patients present with at least one epileptic abnormality during a primary standard EEG, even when stimulation procedures (hyperventilation, intermittent photic stimulation, sleepiness) are performed [79]. Repeating the standard EEG can increase the recording rate of interictal abnormalities and authors have reported that a minimum of 4 consecutive standard EEG recordings are necessary to record abnormalities in more than 90% of epileptic patients [107]. Seizures are recorded during 2.5 to 7% of routine EEG recordings [97], whereas certain seizures are closely related to the decreased level of alertness, or sleep onset [105], and the limited duration of standard EEG prevents the recording of these events.

Diagnostic contribution of LTVER. The duration of LTVER from 1 to 6 days can significantly increase the number of positive diagnoses vs. conventional EEG [2,54,94]. Diagnostic or treatment changes were observed in 55% to 60% of recorded patients [54,70,131]. Most often, LTVER can differentiate epileptic seizure (ES) from psychogenic non-epileptic seizure (PNES, 55% of LTVER) or focal epilepsy from generalized epilepsy (35%) [131]. During a mean recording duration of 3.5 to 6 days, 70% to 85% of subjects presented with a common epileptic event and interictal abnormalities were recorded in more than 40% of patients [19,54,75].

A positive diagnosis was possible at the end of LTVER for 82 to 90% of patients [39,76]. When the first LTVER is negative, repeating the examination led to recording an epileptic event in 40 to 55% of patients [39,102]; this rate even went up to 85% in some studies [89]. As a matter of fact, it is important to repeat this examination when the first one is negative. The pre-monitoring diagnosis was validated in 38% of cases and this same diagnosis was revised in 35% of cases [19], whereas for other authors, the revision rate of the initial diagnosis was around 60%, with a notable increase in the number of diagnosed non-epileptic seizures [54,75]. In 70% of cases following LTVER results, changes in patient management were observed.

On average in large centers, 30% of recorded events corresponded to psychogenic non-epileptic seizures, 25% to pre-surgical evaluations of drug-resistant partial epilepsy and 20% of these recorded events allowed the syndromic classification of epilepsy [14].

During laboratory opening hours, LTVER contribution (lasting from 1 to 5 days) for the positive diagnosis of paroxysmal events (outside of pre-surgical evaluation) shows satisfactory results with a 70% diagnostic rate and recorded seizures in 50% of patients [85]. This study suggests the possibility of conducting long-term ambulatory EEG. The possibility of setting up video-EEG at the patient's home was studied in two patients with encouraging results [117].

For drug-resistant partial epilepsy, LTVER is recommended before implanting a vagal nerve stimulator (VNS). In their study, Arain et al. [5] showed that PNES were recorded in 13 patients after VNS implant.

Prognostic contribution of LTVER. After a first epileptic seizure, the risk of recurrence is higher within the first weeks [59]. This risk is greatly increased by the presence of EEG abnormalities [121]. One study suggested that 6-hour Video-EEG would significantly improve the prediction of seizure recurrence risk and thus the ability to drive, compared to routine EEG, especially in idiopathic generalized epilepsy [63].

Long-term consequences of LTVER. In the 24 hours following the presentation of the diagnosis a significant reduction in PNES event frequency was observed [43], even though long-term follow up showed that this improvement was often temporary [93,100]. As a matter of fact 10 years after the diagnosis, 71.2% of these 164 patients reported the persistence of PNES [101].

This improvement also concerned patients with epileptic seizures, due to better therapeutic management of the epileptic syndrome. A significant decrease in the number of antiepileptic drugs taken was also reported, for patients with PNES and ES alike, even at the 6-month follow-up mark [133].

Video-EEG interpretation

The quantitative analysis of EEG is especially useful for LTVER. Technical advances have enabled the development of highly performing algorithms to automatically detect seizures, to reduce the fastidious, lengthy and costly full reading of the trace. Today, it is recommended to validate the interpretation obtained via these techniques by a human qualified operator [106].

On study compared the reading of LTVER by two independent operators, one using the continuous review method, and the other sampling the first five minutes of each hour together with events identified by push buttons and automated spike detection software. A substantial number of

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events were missed by the sampled review, yet in spite of this there was excellent agreement between the two methods on final diagnosis for each patient and on the impact on care management [8].

Furthermore, some studies showed some intra-observer discordance during the analysis of events recorded in video-EEG, especially for PNES [14].

Video-EEG complications

LTVER is a safe procedure, and the rate of severe complications is relatively low, most often having no impact on the duration of the hospital stay [90]. This complication rate varies according to the studies from 9% [35] to 21% [90]. Table 3 reviews all data from studies listing complications that occurred during LTVER.

Stimulation procedures used to promote seizure recording, such as sleep deprivation and reducing or withdrawal of antiepileptic drugs, increase the risk of seizure clusters, prolonged seizures and status epilepticus. Seizure clusters, defined by at least 3 partial or generalized seizures within 24 hours, occur in 48 to 60% of patients admitted to video-EEG units [34,60,104,119]. Long-term partial seizures or secondarily generalized seizures are reported in less than 3% of patients [104]. The rate of complex or generalized status epilepticus ranges from 0% to 3% according to the series [90,104,119].

Minor traumatic complications, such as grazes or bruises secondary to falls were noted. More severe orthopedic lesions such as shoulder dislocation and vertebral fracture can occur during generalized tonic-clonic seizures [110]. Psychiatric complications such as post-ictal or ictal psychosis were reported in 1.3% [6] to 38% of patients [35]. In a study of 590 recorded seizures, only one event was associated with a suspicion of inhalation during secondary generalized seizure that occurred during a meal with presence of food in the mouth; no further complications were noted [91].

Cost-effectiveness evaluation

LTVER validation of psychogenic non-epileptic seizures decreases by 84% the mean medical care cost of these patients in the 6 months following the diagnosis [80].

Reading and interpretation of long-term EEG

Reading and interpretation of long-term EEG requires time and experience. The large amount of data to be analyzed carries two types of risks: the main one, heightened by the length of the recording and quantity of data to be analyzed, is of ''over-interpreting'' the EEG (detection of false positives), usually due to a lack of knowledge of some unusual physiological activities, especially in the temporal regions [12,68]. The second risk is to overlook authentic abnormalities or onset of seizures with little or no symptoms (i.e. not identified by the patient, family and/or the EEG technician), because of the profusion of data and digital display/paper speed for trace reading.

Interpreting recorded clinical events may be difficult: in fact the inter-observer reproducibility of recorded event interpretation during LTVER is weak [13], even more so since the reproducibility of standard EEG interpretation has been shown to be quite limited [128].

Table 3 Data on the security of long-term video-EEG recordings.

Reference	Method	Number of patients	Complications (% number)
Atkinson et al., 2012 [6]	Retrospective analysis 24/7 LTVER	20 patients (170 seizures)	1 injury (0.6%), 1 status epilepticus (0.6%), 6 falls (3.5%), 2 post-ictal aggressions (1.2%), 4 objects in the mouth (2.4%), 14 seizures while standing (8.2%), 5 seizures with post-ictal ambulation (2.9%)
De Conceiçao et al., 2012 [27]	LTVER retrospective analysis in selected patients (mesial temporal lobe epilepsy and psychosis)	18 patients	2 episodes of postictal psychosis (11%) not continuing during the prolonged hospital stay
Noe et al., 2011 [91]	Retrospective LTVER analysis	132 patients (590 seizures)	33 seizures (5.6%) during a meal or when drinking, 14 seizures (2.3%) with food in the mouth at the beginning of the seizure, 4 seizures (0.6%) with postictal vomiting, no food down the windpipe, suspicion of aspiration with no secondary complications, no aspiration pneumonia
Rose et al., 2003 [104]	Retrospective LTVER analysis	169 patients	5 (3.0%) status epilepticus, 30 (17.8%) seizure fits for 4 hours, 82 (48.5%) seizure fits for 24 h
Shafer et al., 2011 [114]	Questionnaire sent to LTVER center	70 participants answered (AES members)	Reported adverse events: 69% of responders reported falls, 63% status epilepticus, 54% postictal psychosis, rare but severe adverse events that were reported, 10% of responders reported pneumonia, 7% cardiac arrest, 6% fracture, 3% death Inclusion of the risks related to the intracranial status

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Quality standards for long-term EEG interpretation are currently lacking. It is recommended to follow a rigorous process respecting the following elements:

- the analysis of the EEG signal must be impartial. Signal variations should be described in validated standardized terms (glossary of terms established by the International Society of Clinical Neurophysiology) [33];
- the analysis of a clinical event recorded on video must be described in an objective and factual manner;
- when in doubt, it is recommended to ask for a second reading by an independent expert;
- determining the pathological nature of an activity should be based on specific knowledge;
- it is recommended to comment the identified abnormalities according to the clinical situation.

In conclusion, to qualify the level of confidence in the interpreted data the physician should use the following terms: ''certain'', ''probable'', ''possible'', ''doubtful'' and ''impossible''.

Conclusion

The main indications for long-term EEG are:

- syndromic classification of epilepsy;
- evaluation of interictal abnormalities when epilepsy is suspected, or for therapeutic assessment;
- positive diagnosis of paroxysmal clinical events;
- pre-surgical evaluation of drug-resistant epilepsy.

As highlighted here, the indications for long-term EEG converge, regardless of the modality (sleep-deprived EEG, Amb-EEG and LTVER), and no study has evaluated the superiority of one modality compared to another.

We propose the following recommendations:

- after a first epileptic seizure in adults, following normal standard EEG and brain imaging, SDE is indicated to establish a syndromic diagnosis and validate adequate antiepileptic treatment (EEG for syndromic diagnosis);
- faced with the high frequency of recurrent stereotyped paroxysmal events, LTVER is indicated to establish a positive diagnosis on the nature of these clinical events (EEG for positive diagnosis of seizure). If the frequency of these clinical events is low, SDE or Amb-EEG can be proposed to provide indirect evidence of a potential epileptic origin;
- for treated epilepsy, when the evaluation of treatment efficacy is difficult to establish on a clinical level (for example asymptomatic electrical seizure or transient epileptic amnesia), Amb-EEG is indicated to assess the therapeutic effectiveness based on neurophysiological markers (EEG for therapeutic follow-up);
- for treated epilepsy when seizure management is not satisfactory, SDE is indicated for possible revision of the syndromic diagnosis. In frequent seizures, LTVER should be preferred for the positive diagnosis of clinical events;
- LTVER is indicated to explore the possibilities of a surgical treatment in drug-resistant partial epilepsy. The duration of the recording should be as lengthy as possible to collect all relevant data (EEG for topographic diagnosis);
- in a patient whose antiepileptic treatment has been stopped after a prolonged seizure-free period, SDE can be indicated to evaluate the potential risk of seizure recurrence (prognostic EEG).

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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